The CDF Muon Detectors

Phil Schlabach for the muon people

thanks to everyone who gave me stuff or whose stuff I've stolen

an incomplete list of the muon people (pager carriers and others)

- BMU: *D. Carlsmith, W. Chung, S. Chuang, D. Cyr, B. Handler, C. Ginsburg, G. Ott, L. Pondrom*
- CMP/U: L. Cerrito, H. Kim, T. Liss, T. Vickey
- CMX: *M. Karagöz Ünel, M. Schmitt, D. Stentz,* I. Zaw
- Scint.: A. Artikov, *C. Bromberg,* J. Budagov, G. Chlachidze, D. Chokheli, F. Prakoshyn, *G. Pauletta,* O. Poukhov
- HVMON: *Y. Shon*
- Trigger: *E. James*
- Recon.: *J. Bellinger,* K. Bloom, L. Cerrito, W. Dagenhart, *V. Martin*

Brandeis, Dubna, *Fermilab,* Harvard, Illinois, Michigan, *Michigan State, Northwestern, Trieste/Udine, Wisconsin*

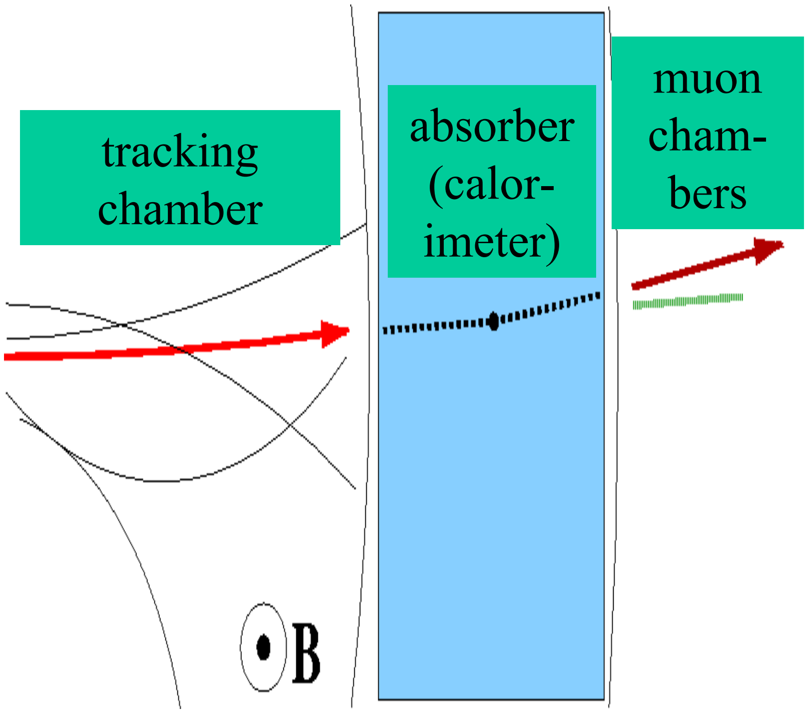
I apologize to those I've missed.

The CDF Muon Detectors

- basics of muon detection
- CDF muon detectors
  - description
    - chambers
    - counters
    - triggers
  - operation
  - alignment
  - calibration

basics of muon detection

- muon detectors do particle ID
- muon $\equiv$ any <u>charged</u> particle from the IP that makes it through a thick absorber of non-muons
  - the absorber is quite often known by other names or for other functions
    - e.g. CEM, CHA, WHA
  - you can stick anything out there to detect the muon you want to



what you might stick out there

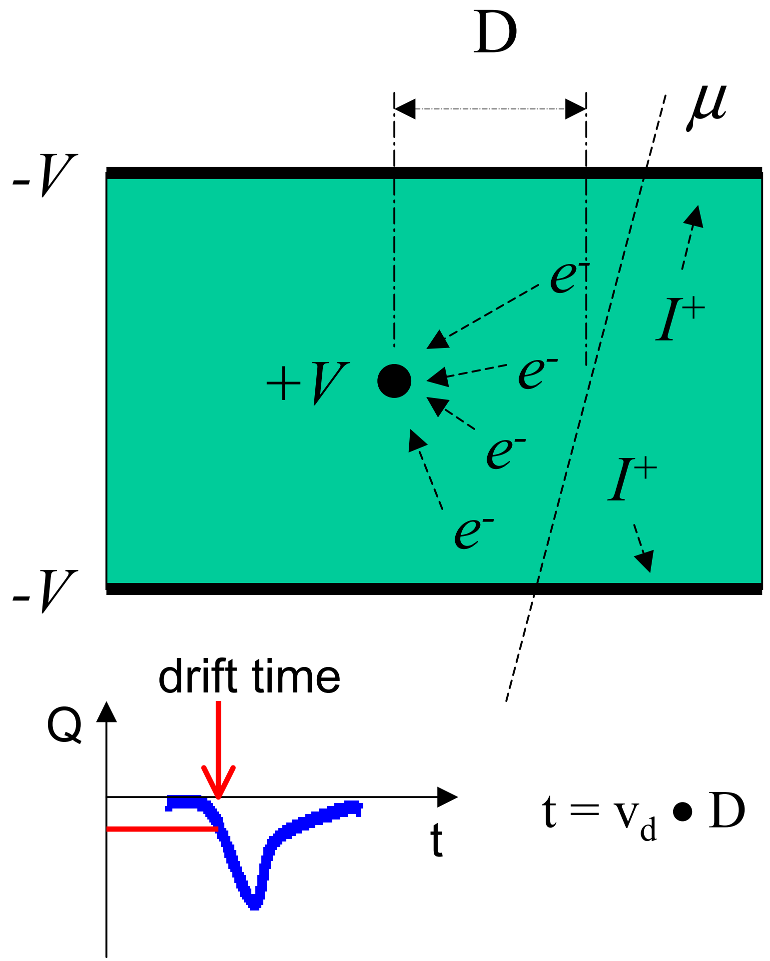
- silicon - perhaps not the right choice
- scintillator - too expensive
  - good segmentation & multiple layers (to get a track) needed
  - a layer or two with coarse segmentation is often added to get precise timing for the muon
- drift chambers - perfect
  - relatively inexpensive
  - uncomplicated thus easy to build
  - good precision
    - typical for muon chambers: a few hundred μ

drift chambers for muon detection (1)

- advantages of single wire chambers (vs multiwire)
  - production techniques easier
    - doesn't require fancy "equipment"
    - can easily be done by a university group with unskilled labor
    - separates chamber production from "module" production
  - failures can be discarded
    - less depends on a single chamber
    - failure of a single wire takes out only 1 cell
  - quite exotic geometries can be formed from simple rectangular chambers
- advantages of multiwire chambers
  - small cell sizes are easier
  - may be faster to build
- I'm sure there are differing opinions…

drift chambers for muon detection (2)

- single wire drift chamber
  - charged particle ionizes gas
  - primary ionization electrons drift toward anode (sense) wire low E field
  - as they approach the wire they speed up and create an avalanche of charge (high E field)
  - charge produces a pulse as it hits the wire
  - drift time gives the distance from the wire



$t = v_d \bullet D$

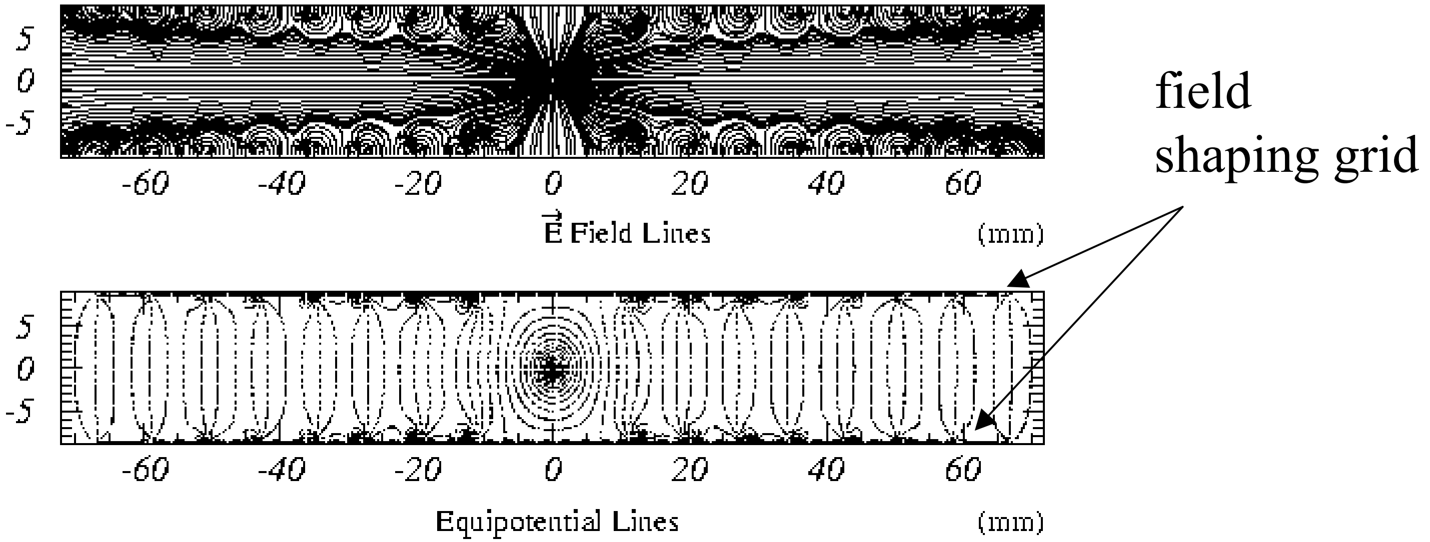
drift chambers for muon detection (3)

- determination of the longitudinal coordinate (X) is possible (longitudinal means along the wire)
  - charge division
    - must read the charge (Q) from both ends of the wire, time is not enough
      - X/L = (Q1-Q2)/Q1+Q2); L = wire length
  - crossed wires
    - wires in different layers are not parallel
    - they don't actually have to cross
  - time division
- NL/YKK's COT talk has more on drift chambers; there are other good references

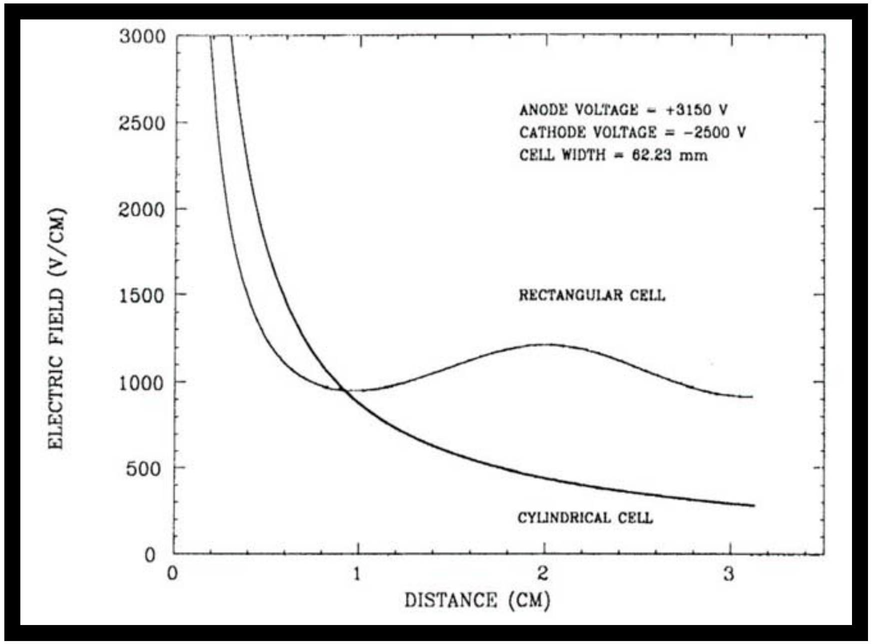
muon chambers (1)

- typical gases: argon ethane, argon CO_2
- most employ field shaping to get a (more or less) constant drift velocity across the chamber

- V_{grid} sets v_d
- V_{wire}-V_{grid} sets the gain (10^5)

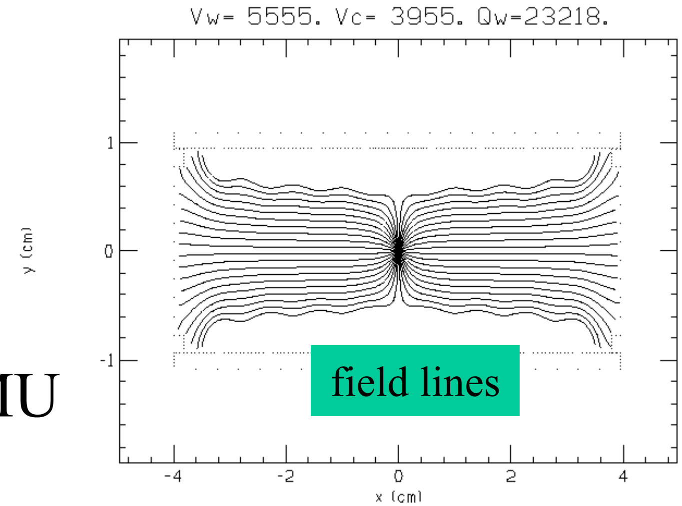


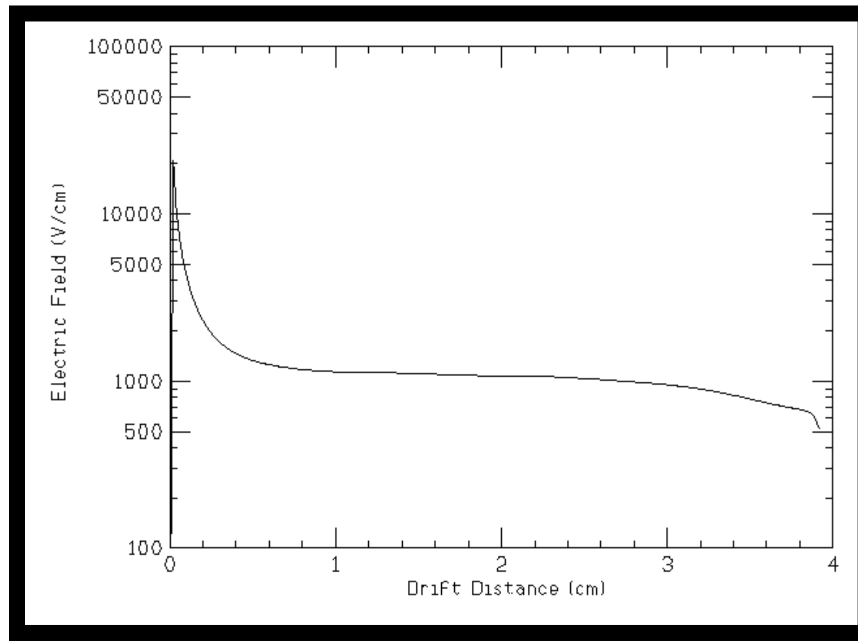
muon chambers (2)



CMU

BMU



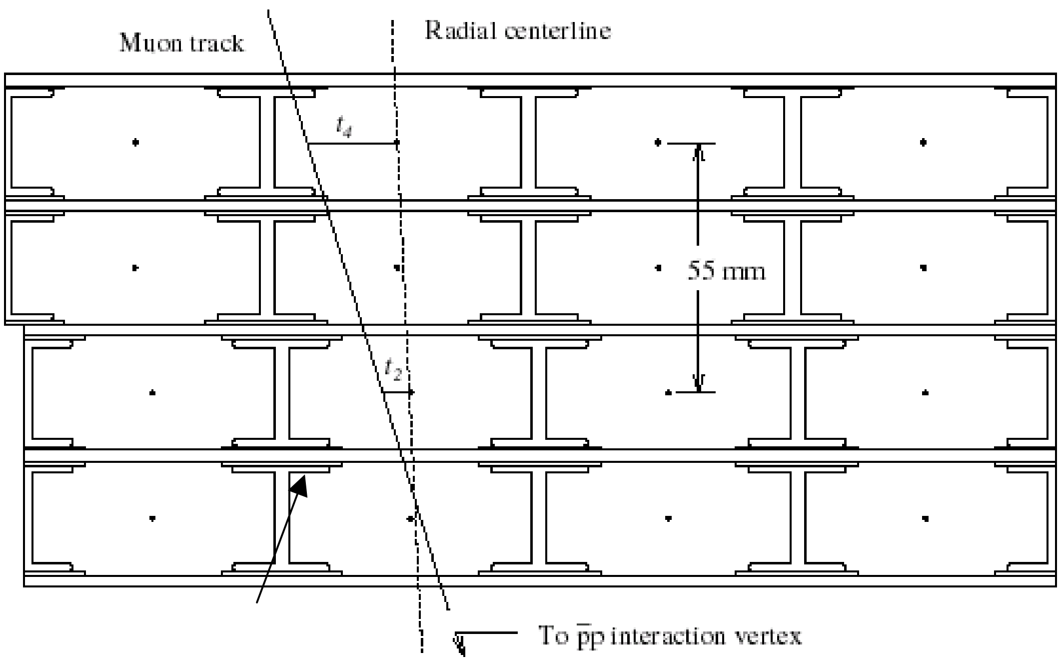


muon chambers (3)

- $v_d \approx 50\ \mu$/ns
- T_{max} 1-2 μs (I.e. slow)
  - sets the limit for acceptable occupancy
  - 1 particle/T_{max}
  - for higher occupancy use multiwire drift chambers (smaller cell size)
    - high rate chambers (e.g. CMS end cap)
      - cathode strip chamber
      - resistive plate chambers

muon chambers – example 1: CMU

- single wire cell but a multi-cell chamber
- constructed at Illinois around 1985
- easy to build



muon chambers – example 2: CMP/X (1990)

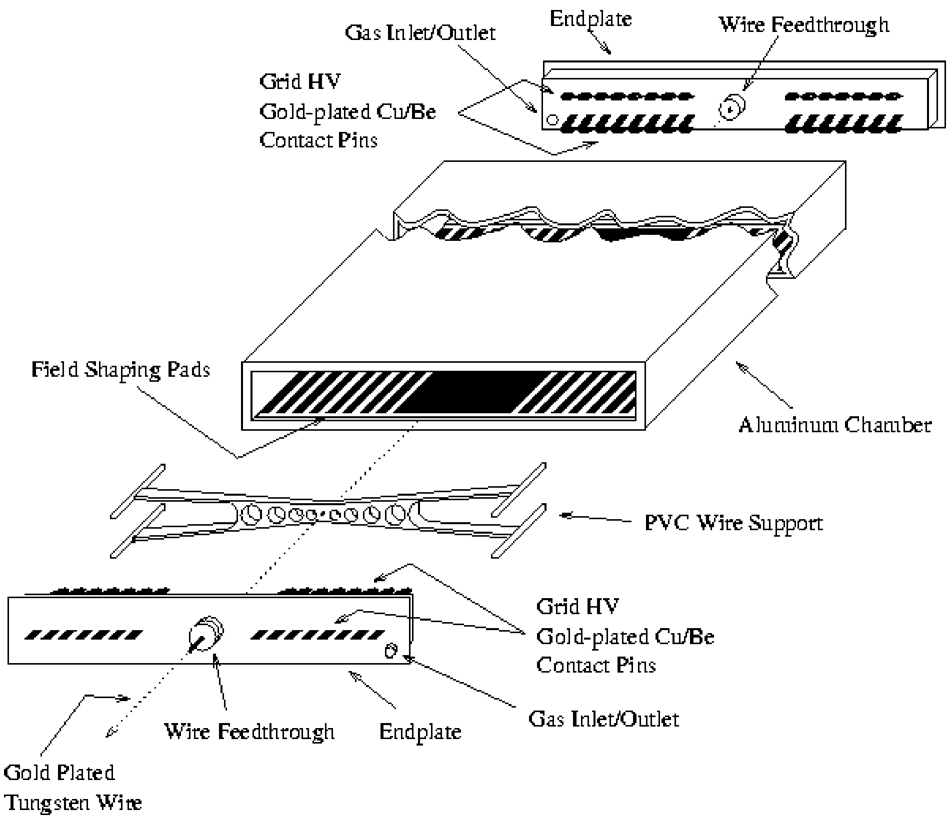
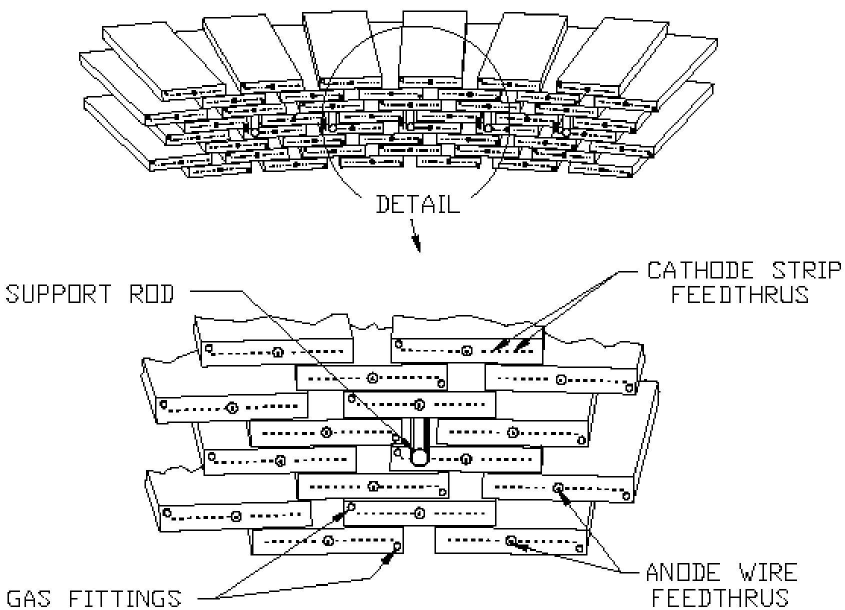


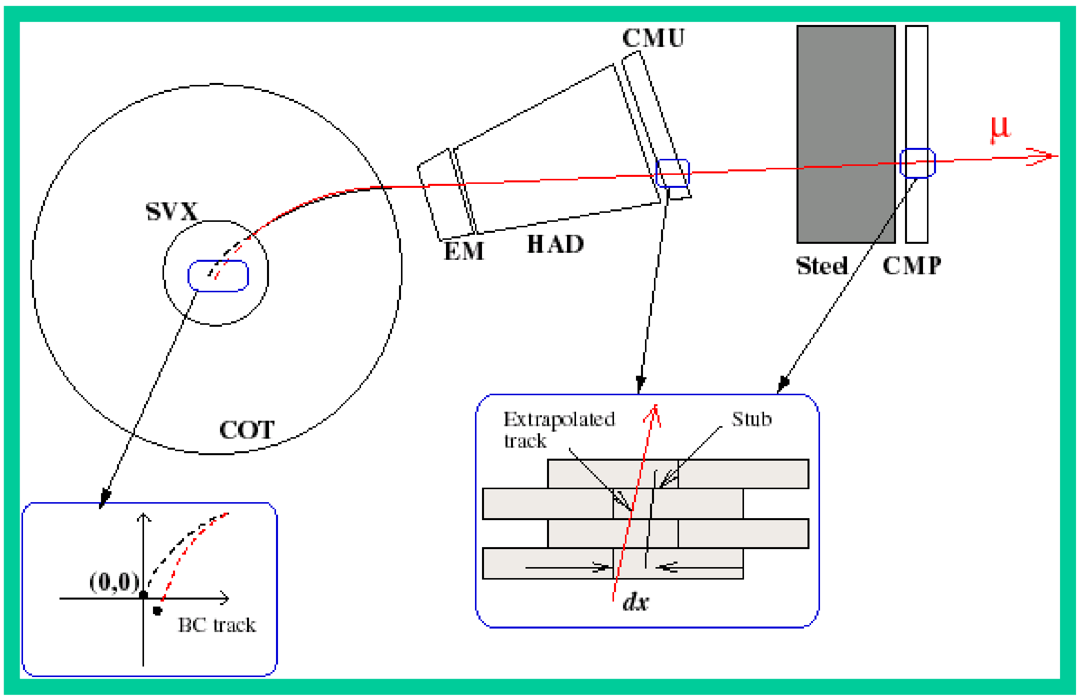
Figure 6: Schematic view of a CMP-CMX tube. Note that wire supports are used only for CMP.

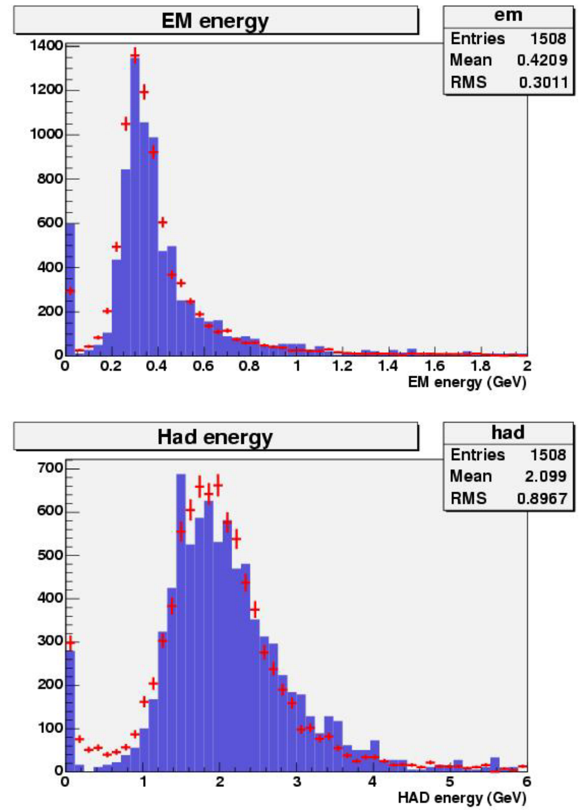
- single wire cell
- constructed at Illinois/Harvard 1990-91
- much more of a production line
- between 1985 and 1990 local suppliers of extrusions and injection molded plastic parts had become ubiquitous

two exotic geometries!



elements of modern muon detection



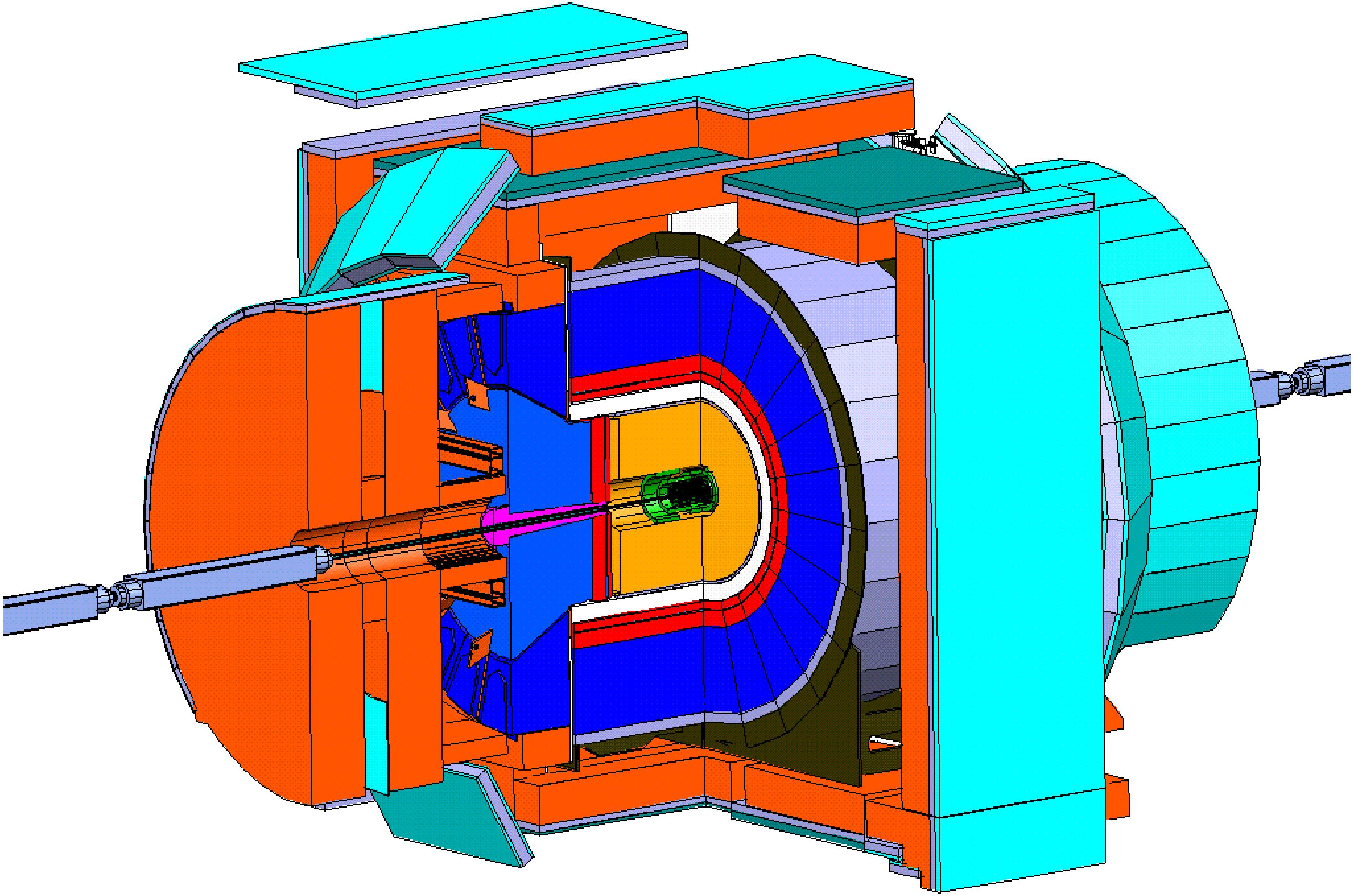


- muons interact hardly at all in the calorimeters, everything else gets absorbed

backgrounds

- real muons
  - cosmic ray
  - decay in flight
- non-interacting punch through
  - hadrons (mostly π in jets) that don't interact in the calorimeter
- beam related backgrounds
  - out of time by 30-40 ns
- "debris" from real particles
  - particles from collisions interacting in the beampipe
  - gets worse at larger η
    - beampipe a thicker target
    - not out of time by much (a few ns)

CDF Muon Detectors

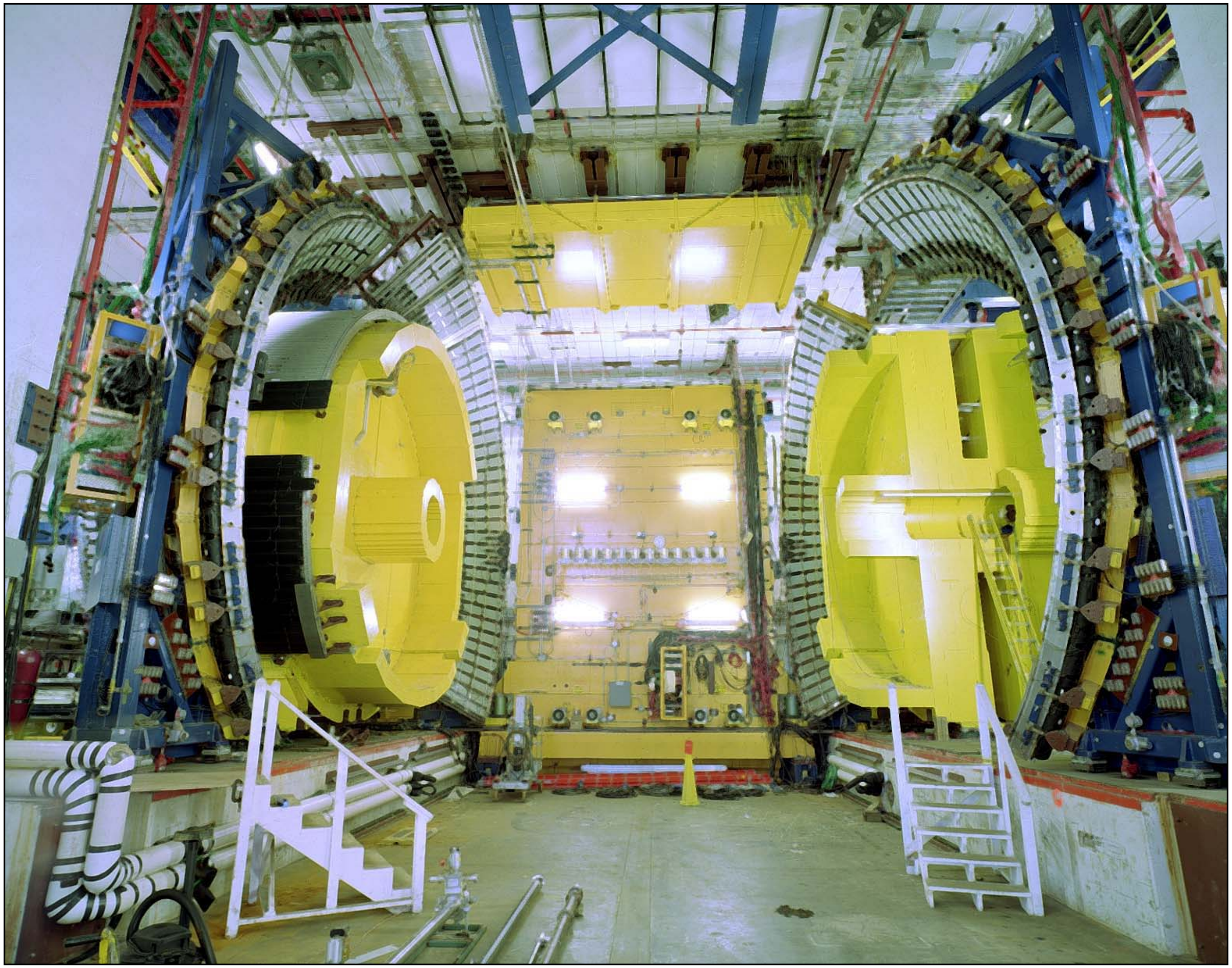


detector summary

chambers/counters	$\lvert\eta\rvert_{min}$	$\lvert\eta\rvert_{max}$	$\Delta\phi°$	**T_{drift} (max)♣**	**#chan.**
Central muon (CMU)	0.0	0.6	360	800 ns	2304
Central muon upgrade (CMP/CSP)	0.0	0.6	360	1500 ns	1076/274
Central muon extension (CMX/CSX)	0.6	1.0	360	1600 ns	2208/324
Intermediate muon (BMU/BSU-TSU)	1.0/1.0-1.3	1.5/1.5-1.5	270/270-360	800 ns	1728/432-144

♣crossing time 396 ns: occupancy not a problem 10^{-2}-10^{-3}

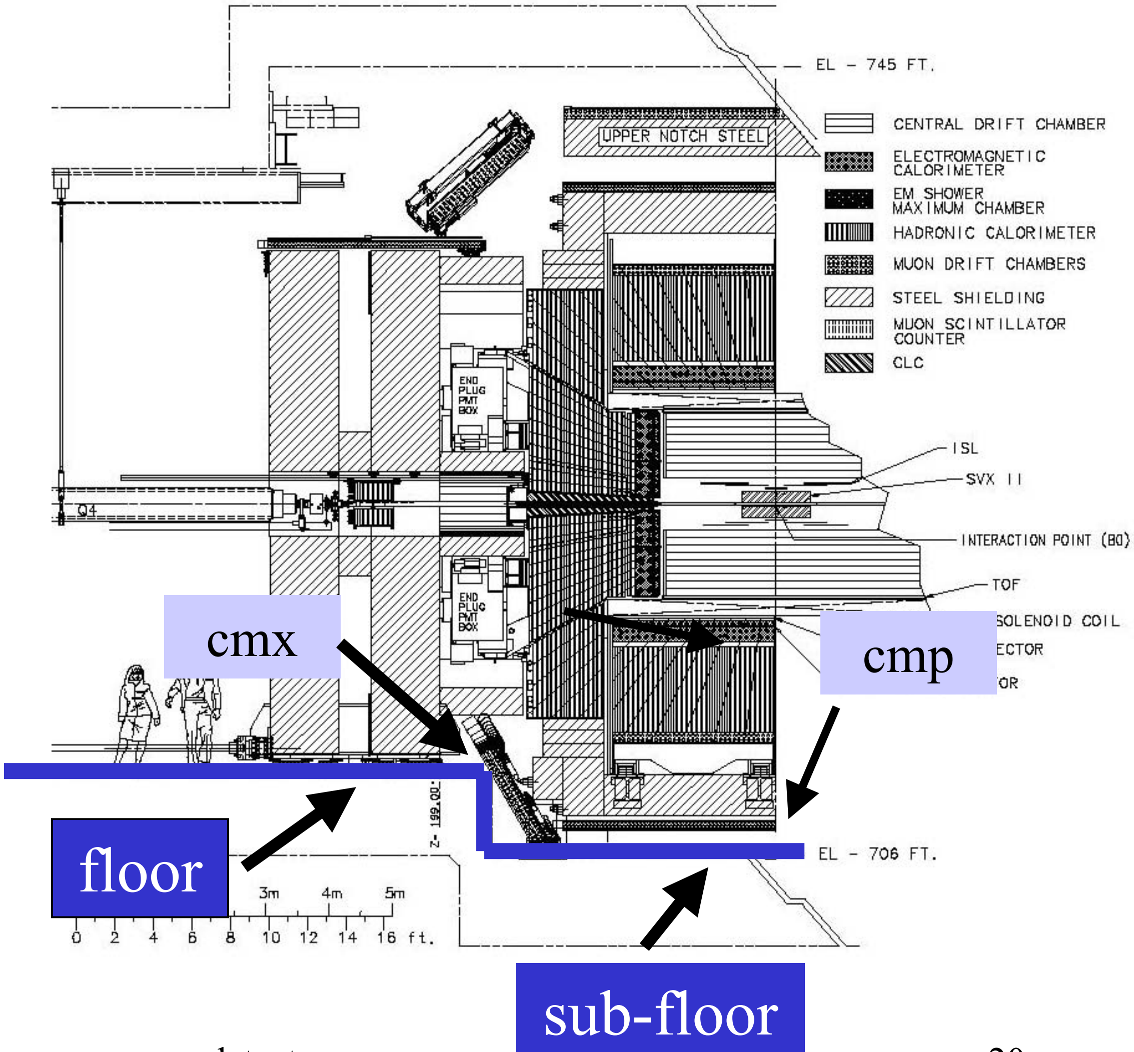
a gorgeous picture



detector history

- pieced together?
- indeed!

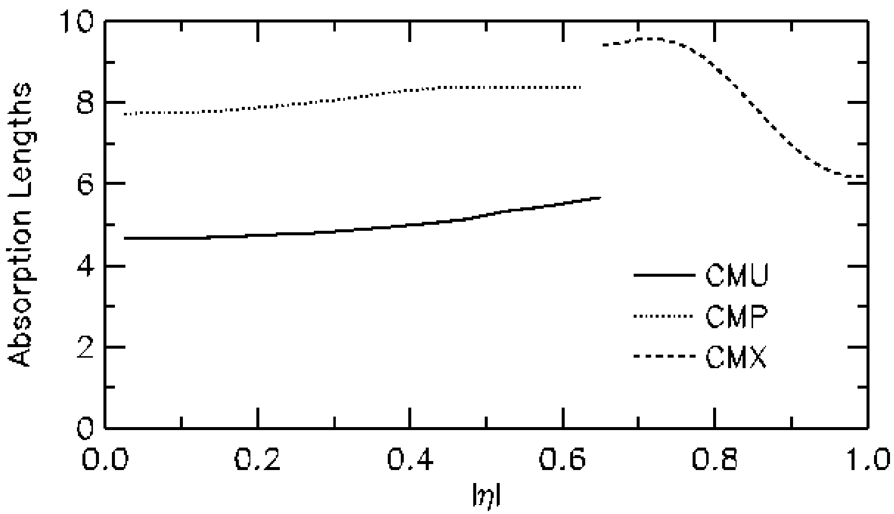
detector	1st run
CMU	‘87 run
CMP/CSP	Run 1
CMX/CSX	Run 1
BMU/BSU-TSU	Run 2

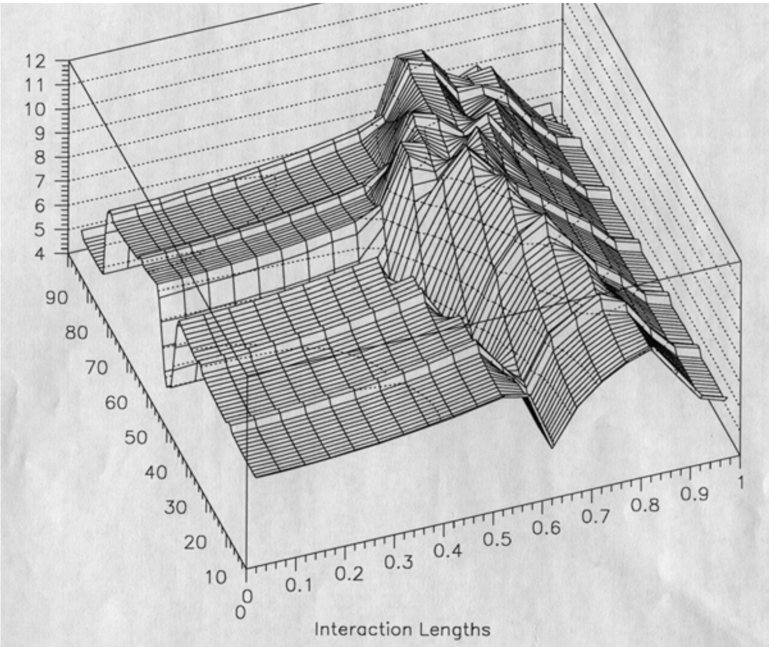


absorber

sometimes you have to bite the bullet and pay for your absorber instead of getting it for free

sometimes the absorber is incredibly complicated (and a real hassle to put in the monte carlo geometry)





1 quadrant of CMX: interaction lengths vs ϕ, η

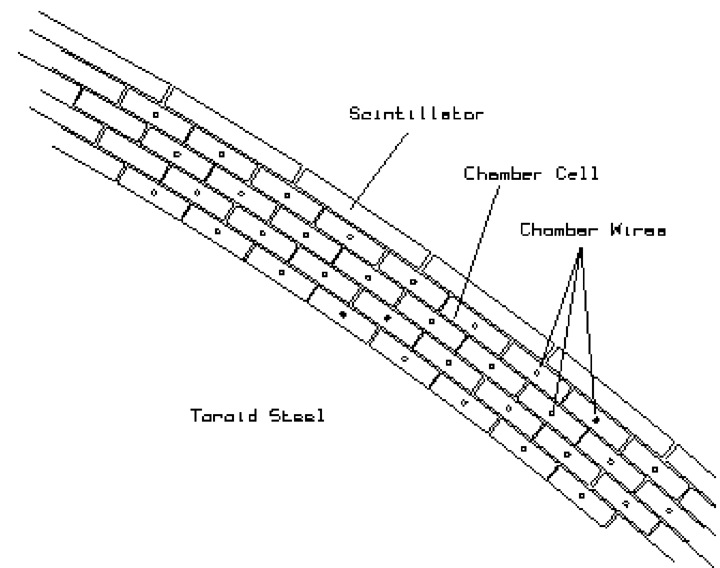
chamber description

- single wire drift cell with field shaping
  - CMP/CMX/BMU drift linearized by a series of cathode strips
  - CMU has only a single cathode
- HV
  - supply in counting room
  - chambers ganged in collision hall
- 50%/50% argon- ethane with <1% isopropyl

	x-section (cm)	operating voltage (Anode/Cathode)
BMU	**2.54 x 8.25**	**5500/3200**
CMP	**2.54 x 15.24**	**5600/3000**
CMU	**6.35 x 2.54**	**2500/-2325**
CMX	**2.54 x 15.24**	**5400/2800**

detector geometry (1)

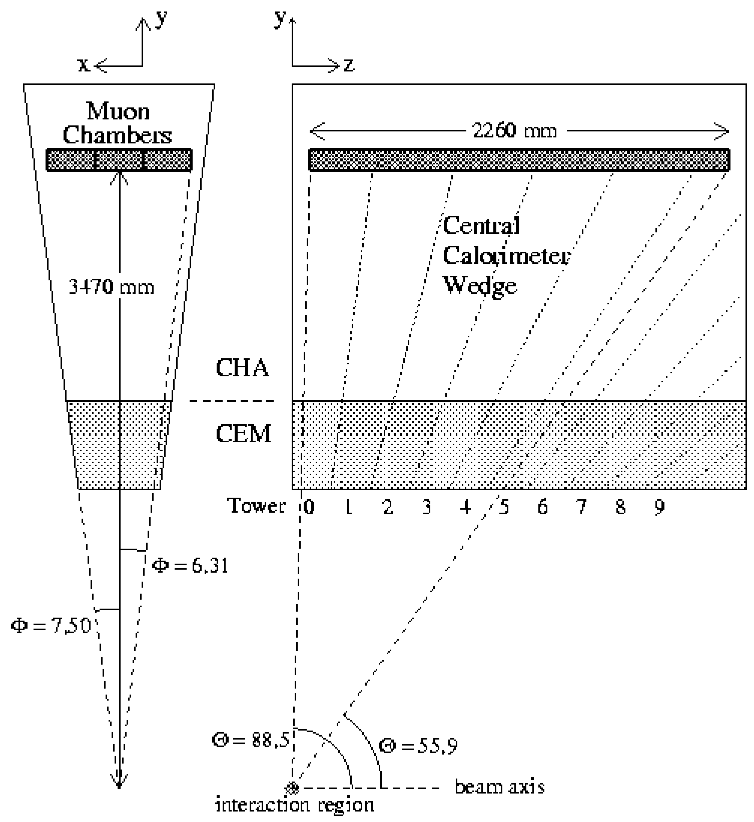
- (pseudo-) cylindrical, rectangular or conical layout
- 4 layers of chambers
  - CMX 4 at small and 8 at large end of cone
  - 2 pairs of radially aligned wires for triggering
  - CMU/BMU gang 2 wires at the “back” end



- longitudinal coordinate
  - CMU by encoding charge into pulse width for charge division
  - CMX from crossing wires
  - BMU from time division

detector geometry (2)

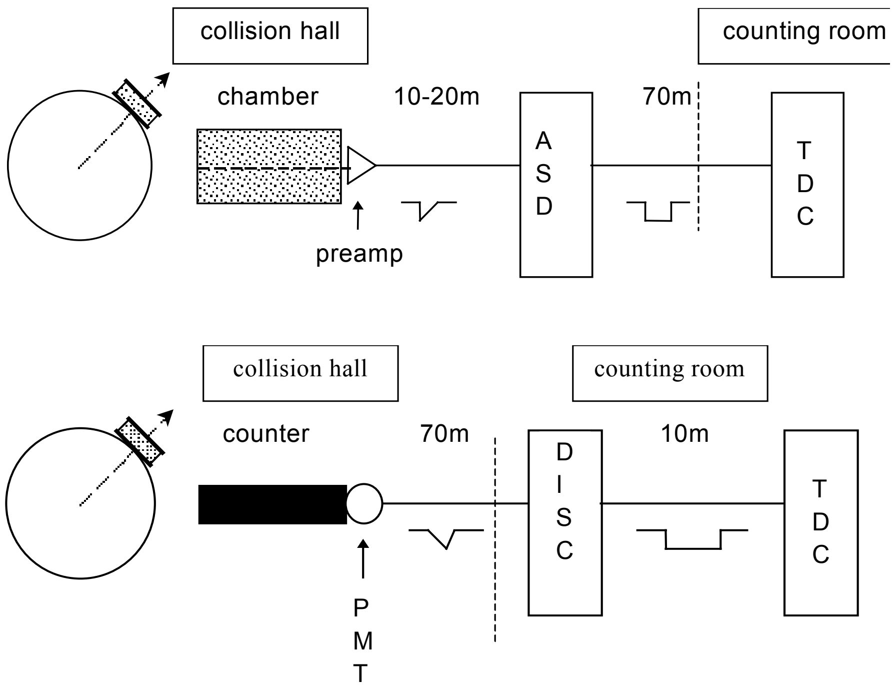
- geometry of CMU and BMU is simple
- CMX only seems complex
  - wires lie on radial lines
- CMP is a nightmare of different pieces



counters

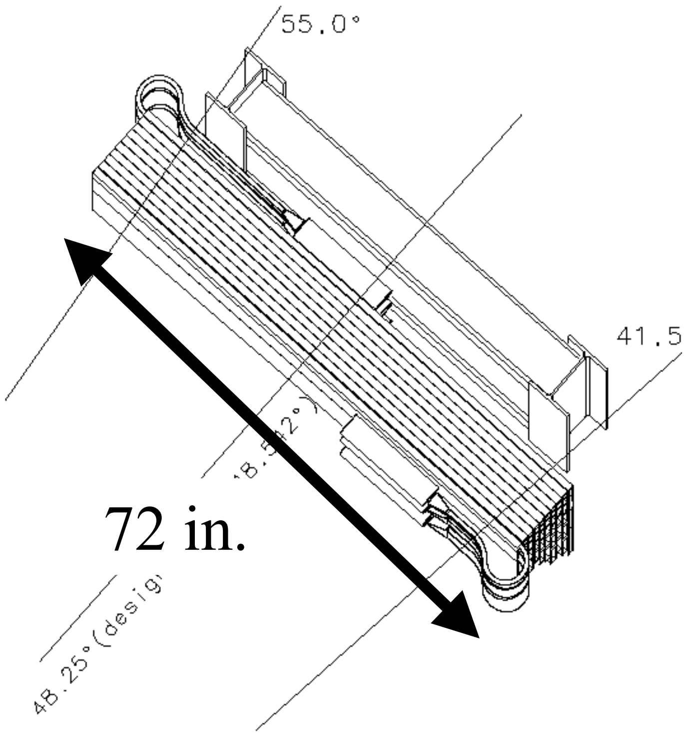
- each chamber set has a matching set or sets of counters
  - except CMU where there is no room in the hole
  - primarily used in the trigger to cut out of time background (CSX & BSU/TSU)
  - CSP not needed so far

readout path

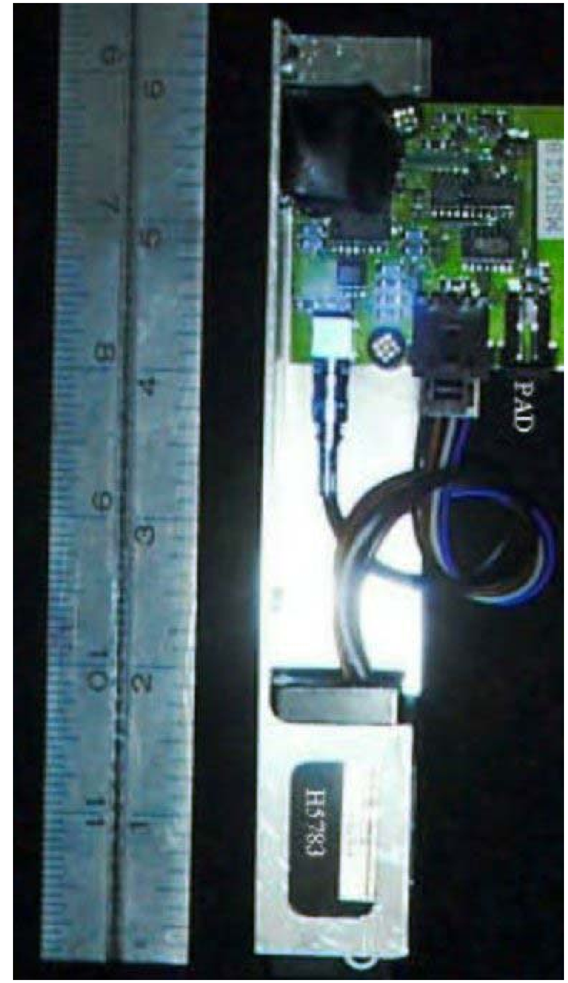


- chamber readout similar
- counter readout differs
  - CSX/parts of CSP as shown
  - BSU/TSU/parts of CSP
    - pmt/cockroft-walton HV gen./amp/disc. in a small package (PAD) on counter
    - control and concentrator (CCU) unit in hall

PAD package



CSX counters



3 level trigger system♣

- L1: match chamber stub (+in time counter) to 2d fast track (2.5°)
  - multiple p_T thresholds for stubs and track
  - single, di-muon, muon+X
- L2
  - auto accept for J/Ψ
  - add displaced vertex for b-hadron flavor tag
  - auto accept or increase track p_T threshold for inclusive high- p_T triggers
  - more functionality almost ready to go, 1.25° match, remove track ambiguity
- L3
  - full offline reconstruction
  - make same selections, looser cuts

♣"the trigger" is a work in progress; this was circa summer '03

trigger cross sections

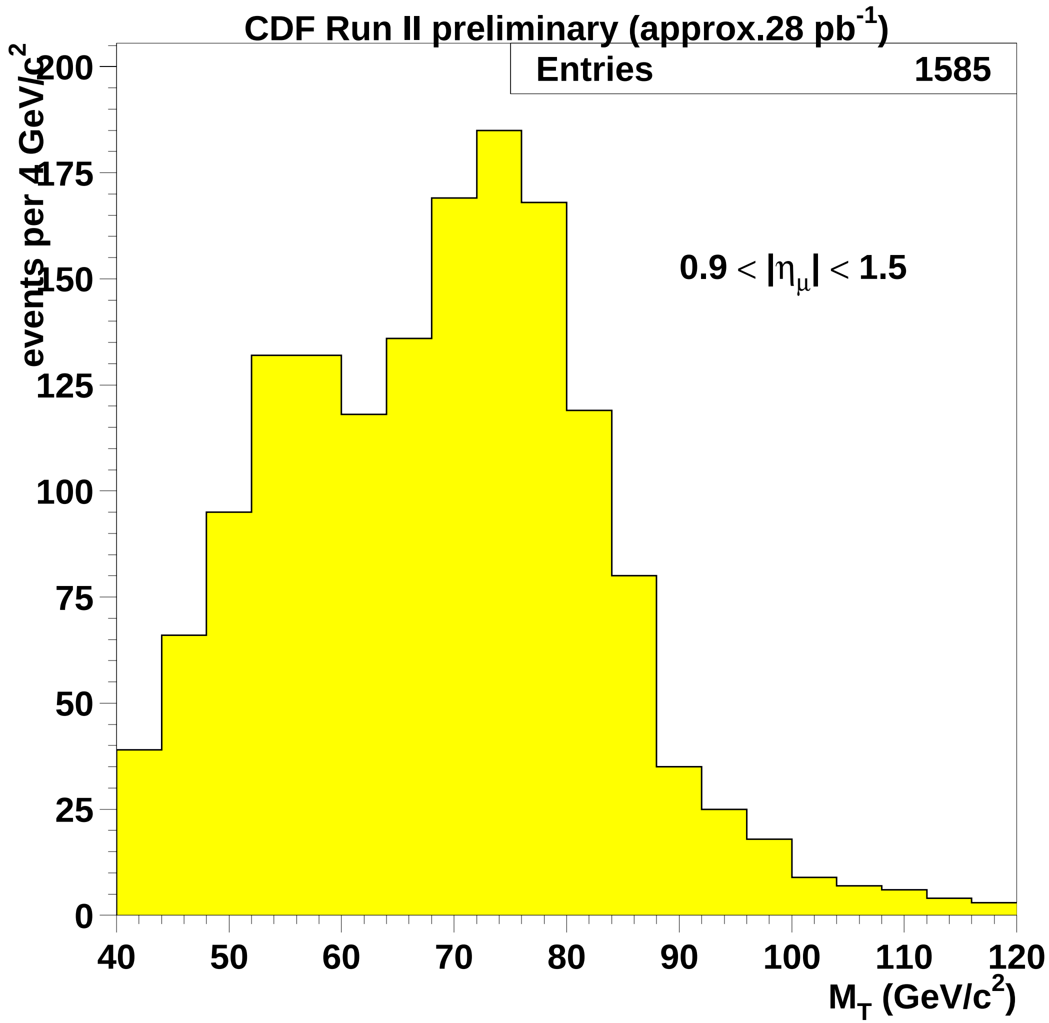
	σ_{L1} (nb)	σ_{L2} (nb)	σ_{L3} (nb)
J/Ψ	1500	1500	60
flavor tag	1500	200	50
inclusive	90-200	90-200	10

3×10^{31}cm^{-2}s^{-1} (circa summer '03)

trigger

- no matter how lovely one's detector is or how well it works, no one cares if you can't trigger on it with an acceptable rate
  - this made a long period of my life miserable
- the cleaner the event signature the harder that is
  - $W \rightarrow e\nu$ is <u>easy</u>; 20 GeV electron•20 GeV MET (missing energy)
  - $W \rightarrow \mu\nu$ is <u>hard</u>
  - the only triggerable object is the muon
    - you can't use MET in L1/2, a 20 GeV/c muon has ~18 GeV of MET
    - XFT fake rates matter, cross sections increase with luminosity
    - at higher η it gets harder because you have fewer COT layers in the XFT track and thus more fakes – there are other reasons as well
    - at high enough η, you don't have a track at all

$W \to \mu\nu$ in BMU $(0.9 < |\eta| < 1.5)$!



operations

- some things are always the same no matter which Run it is (or which year)
  - major sources of bad data
  - detector monitoring/shift crew operation

major sources of bad data (1)

- either too much or too little data
  - – preamps oscillate
  - – chambers trip
  - – and you can't do much about it

- **"High voltage is a bitch",** ***LJN (recently)***

major sources of bad data (2)

- oscillating preamps
  - much more rare than they were in Run 1
  - fundamental problem is a singled ended preamp
    - coupled with a robust high frequency gain
    - slowing down the preamp (I.e. reducing the high frequency gain) has fixed the problem♣
    - we have only implemented the fix in the CMX miniskirts and parts of CMP more or less on an as necessary basis

♣Gary Drake (ANL) fixed it.

major sources of bad data (3)

- detector won't hold HV
  - the chambers and the HV hardware on the chambers need to burn in
    - 4% dead channels in CMX; less in the other detectors
  - due to the ganging of HV in the hall a single component failure takes out a large swath of detector; large enough to declare the data bad
    - accompanied by endless discussions on whether it's bad or not
  - as the burn in proceeds this gets rare
    - (and the luminosity goes up and that data I marked bad doesn't matter anyway…)

major sources of bad data (4)

- front end failures
  - failing boards, failing LV supplies, etc.
  - a burn in also goes on here, but it doesn’t become as rare as HV failure
- beam conditions
  - loss spikes can make it difficult to operate the detectors
    - typically bad stores, but it can go on for store after store
    - muon detectors are typically “exposed”
  - losses create large standing currents
    - we’ve had to worry about aging

detector monitoring

- online monitoring (occupancies, drift times, pulse widths, trigger cross sections, etc.) only catches the really gross problems
  - monitoring code should be smart enough to look for the failure modes
    - we've slowly moved in that direction
  - the really subtle errors are found by the reconstruction types
    - poorly seated cables, swapped cables…

alignment

- to set the scale, multiple scattering for a 20 GeV/c Pt muon reaching CMU is 0.6 cm
- alignment needed because things aren't where they're supposed to be when installed
  - or where the drawing shows they are
    - sometimes not even where the surveyors say they are
  - they can be way off
  - crude tools suffice
- then the as built geometry isn't as designed
  - e.g. CMX isn't a perfect cone
  - done with data (W, Z muons w. little scattering) and as we've gotten more data, we've done this better
- still it's wise to remember that no matter what *we* do, *your* individual 20 GeV/c muon is reasonably likely to have a 0.5 cm mismatch

calibration

- calibrate once, run forever
  - t0s, v_d, width to Q (CMU), etc.
- the only thing that needs periodic calibration is drift velocity
  - only in CMX to get the longitudinal coordinate right
  - 1-2% changes in v_d move the stub z by a few cm
- we don’t have oodles of constants loaded in the front end memory waiting to be wiped out and confuse the shift crew

CDF Central Muon Detector*

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The CDF Forward Muon System*

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Design and construction of new central and forward muon counters for CDF II

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The CDF Run 1 Muon System Upgrade

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The "miniskirt" counter array at CDF-II

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Intermediate Angle Muon Detectors for CDF II

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